Shallow Water MCM and ASW Using Off-Board, Autonomous Sensor Networks and Multistatic, Time-Reversal Acoustics

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LONG-TERM GOALS

To achieve robust multi-static detection and classification of mine-like objects using cooperative networks of virtual acoustic sensors.

OBJECTIVES

To utilize high fidelity acoustic modeling of both scatterers and shallow-water environments to better understand and bound the limits of detectability for mine-like objects via autonomous networks of sensors. To conduct a series of realistic experiments using multiple sonar-equipped AUVs in shallow water and then cross-validate the results obtained with high precision modeling and visualization. To better understand the problems of cooperative autonomous vehicle interaction to define the base-line infrastructure requirements for cooperative detection, classification and navigation.

APPROACH

This program couples high accuracy acoustic modeling and visualization with customized AUV technology. The sonar sensing uses the bi-static and multi-static Synthetic Aperture created by the network, in combination with medium frequency (4-24 kHz) wide-beam insonification to provide coverage, bottom penetration and location resolution for concurrent detection, localization and classification of proud and buried targets in SW and VSW. The signal processing effort in SWAMSI is therefore centered around generalizing SAS processing to bi-static and multi-static configurations, including bi-static generalizations of auto-focusing and track-before-detect (TBD) algorithms. Another issue concerns the stability and coherence of surface and seabed multiples and their potential use in advanced medium-frequency sonar concepts.

MIT's acoustic modeling capabilities derive from both the SEALAB suite (VASA Associates) for general shallow water acoustics and FEMLAB (COMSOL Inc) for detailed structural acoustics and

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target modeling. SEALAB incorporates the OASES environmental acoustic modeling framework developed at MIT [1,3], which is a widely distributed suite of models covering a variety of ocean waveguide and source/receiver representations. Recent developments are computational modules for full wave theory modeling of mono-static and bi-static target scattering and reverberation in shallow water waveguides. The most recently developed module, OASES-3D provides wave-theory modeling of the full 3-D acoustic environment associated with mono-static and bi-static configurations in SW and VSW with aspect-dependent targets and reverberation features [2,3]. It incorporates environmental acoustic features specifically associated with bi-static sonar concepts in shallow water, including aspect-dependent target models, seabed porosity, and scattering from anisotropic seabed roughness such as sand ripples.

With every major AUV deployment, the Mission Oriented Operating Suite (MOOS) previously created at MIT by research engineer Paul Newman advances in robustness and flexibility, and has been undergoing major upgrades in regard to the behavior-based control using the new IvP-Helm developed by Mike Benjamin of NUWC, who works closely with the MIT team as a Visiting Scientist. Another significant component is the development of a comprehensive simulation testbed, coupling the MOOS-IvP autonomous vehicle simulation environment with the SEALAB high-fidelity acoustic simulator, resulting in a complete, distributed software base for planning, simulating and analyzing multi-vehicle MCM missions.

WORK COMPLETED

OASES3D Target Scattering Model

Work has continued on developing a robust and efficient numerical approach for coupling the target scattering models with general propagation models handling the complex ocean waveguide physics. The virtual source approach developed in FY04 [4] provides an extremely efficient approach to coupling wavenumber integration codes, such as OASES3D, or normal mode codes (CSNAP, KRAKEN) with high fidelity target models such as the FESTA and FEMLAB FEM codes. By using a 3D spectral representation of the waveguide Green’s function for the virtual sources, the expanded OASES3D modeling framework now handles complex target shapes and compositions, and in addition handles partially or completely buried targets, incorporating multiple scattering effects. In FY06 we have continued to use this new modeling capability has been applied to quantify the multiple scattering effects, and investigate the effect of target burial depth.

A specific modeling development has been performed in a joint effort between MIT and MPL-SIO, aimed at simulating time-reversal mirror scenarios for target DCL. The modeling concept, illustrated in Fig. 1, uses OASES to simulate the broadband insonification of the target by an array of individual sources in a source-receiver array (SRA). The insonification is then convolved with the target target response using OASES-3D, and the field received on the SRA is simulated. This produces a ‘matrix’ of Green’s functions to and from all elements of the SRA, which can then be applied to perform ‘synthetic’ iterative time-reversal to enhance the target response over the background reverberation.

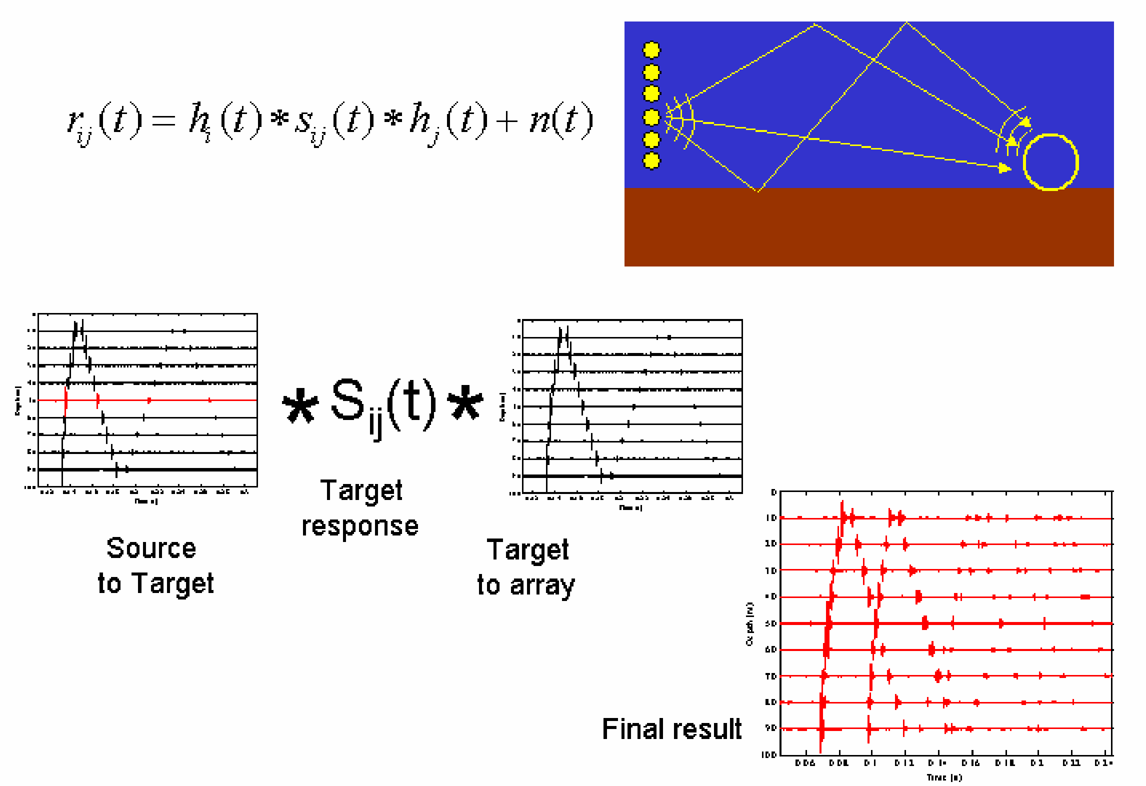

Figure 1. Principle of synthetic, iterative time reversal modeling.

EVA'06 Experiment

A major effort was untdertaken in FY06 in collaboration with NURC on the planning of the EVA'06 experiment in October5 2006 at Marciana Marina, Italy. The objective of this experiment is to provide an extensive 3-dimentional data set for bi-static scattering from proud, and partially and completely buried complex targets. Thus, the experiment wil use the TOPAS parametric source for cotrolled insonification of the targets, in combination with an extensive receiver suite, including a small bi-static array synthetic aperture below the R/V Leonardo, and a dome array deployed by NRL-Stennis allowing for 3-D measurent of the scattering in the near-fiield of the targets. In addition to providing a unique data set for validation of the new target scattering models developed jointly between MIT and NURC, the experiment will also explore the possibility of using synthetic-aperture, time-reversal acoustics for target classification.

RESULTS

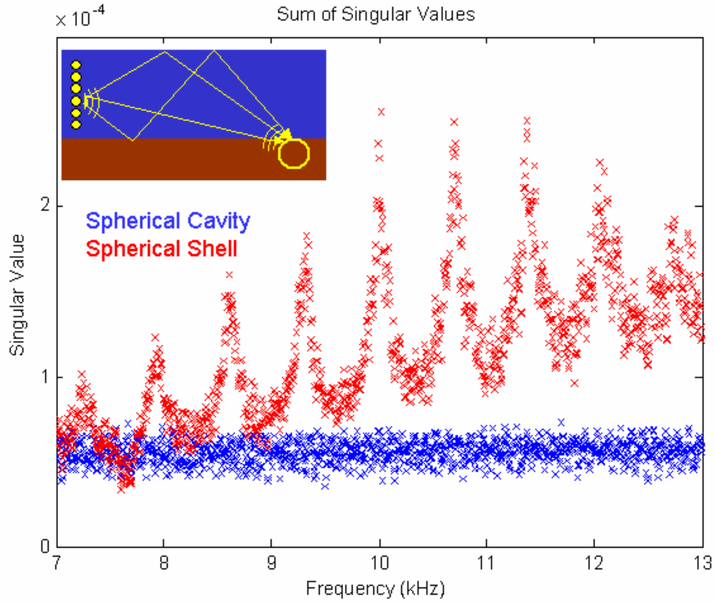

Figure 2 Spectral response enhancement achieved by synthetic, iterative time-reversal for a flush-buried spherical target, using a vertical; source-receiver array 200 m from the target, buried in 100 m water.

In collaboration with MPL-SIO (Karim Sabra and W.A. Kuperman) an extensive simulattion study has been performed regarding the potential of using synthetic, iterative time-reversal for enhancing the resonances of manmade, buried targets. The study has been performed using the new OASES-3D TR modeling framework described above, and the preliminary results are encouraging. Thus, Figure shows the performance of the approach for a flush-buried, 1 m diameter, spherical shell (GOATS sphere). The red symbols show the frequency response of the spherical shell, compared with the response of a spherical cavity of the same size, shown in blue, and showing no resonance structure. The studey showed that the enhancement for this scenario will allow detection of the flush-buried sphere at signal-to-reverberation ratios as low as 0 dB.

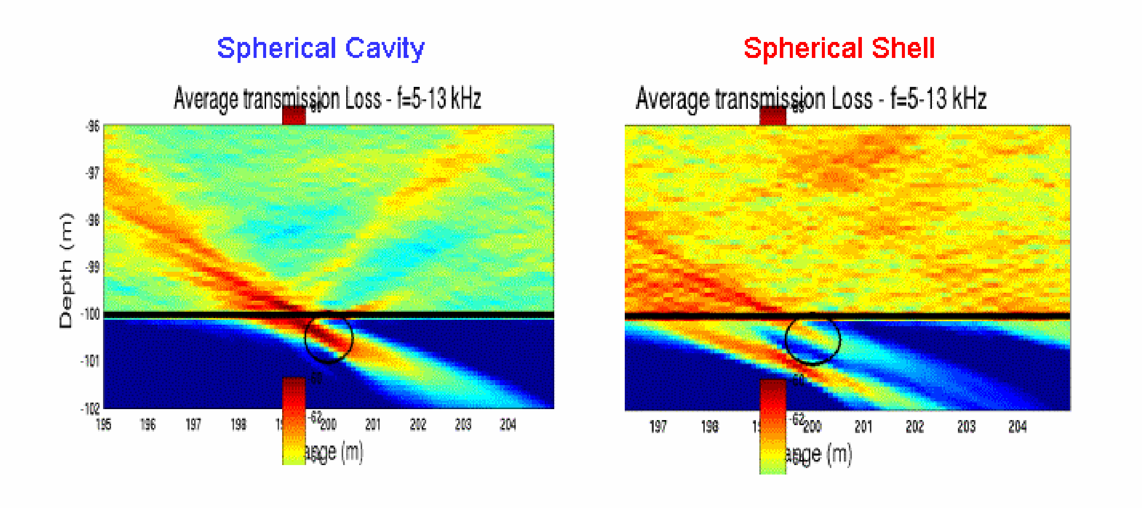

Figure 3. Back-propagated field focusing on flush-buried spherical target. Left frame shows the result for a spherical cavity, where the focusing highlights the specular scattering point. The frame to the right shows the equivalent result for a spherical shell (GOATS sphere), where the strong focusing on the lower part of the shell confirms the hypothesis [9] that the high-frequency scattering from a flush-buried spherical shell is dominated by the circumferential flexural wave, excited by the evanescent icident field, and re-radiated supersonically into the sedimaent and back into the water column at supre-critical angles.

The study also confirmed an earlier hypothesis regarding the strong high-frequency scattering anomaly observed for a flush-buried sphere in the GOATS experiments, suggesting that it is due to strong coupling at sub-critical incidence into the flexural surcomferential, flexural waves in the shell, which are supersonic above the coincidence frequency, and therefore re-radiate from the lower portion of the shell, through the sediment and back to to water column, at supercritical angles [9]. Thus, the new TR model was used to back-propagate the field received on the SRA, and as seen in Fig. 3 the focusing at the lower part of the sphere is evident, thus confirming the hypothesis, which also has been confirmed independently in [10] by analysing bistatic, horizontal array data collected dutring the GOATS'98 experiment.

IMPACT/APPLICATIONS

The long-term impact of this effort is the development of new sonar concepts for VSW MCM, which take optimum advantage of mobility, autonomy and adaptivity. For example, bi-static and multi-static, medium-frequency sonar configurations are being explored for completely or partially proud or buried mines in shallow water, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and its environment.

TRANSITIONS

The virtual source modeling approach developed under this project has been transitioned to NURC as part of the OASE3D target modeling framework. Here it ist has is coupled to the FEMLAB finite element framework to allow modeling of complex elastic targets. It has also been transitioned to NUWC (J. Blottman), CSS (D. Burnett), and WSU (Marston) for the same purpose. It is currently

being integrated with the MIT-MCM simulation framework developed under GOATS (N00014-05-1-0255) for simulating autonomous, adaptive target classification [7,8].

RELATED PROJECTS

This effort is closely related to the GOATS project, initiated as the GOATS'2000 Joint Research Project (JRP) with the NATO Undersea Research Centre (NURC), and continued at MIT under the GOATS'2005 grant (N00014-05-1-0255), funded jointly by ONR codes 321OA (Livingston), 321OE (Swean), and 321TS (Commander). The collaboration with NURC, is continued under the Hybrid Target Modeling and Focused Acoustic Field (FAF) Joint Research Projects (JRP).

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Irena Lucifredi and Henrik Schmidt , “Sub-critical Scattering from Buried Elastic Shells". *J. Acoustical Society of America,* 2006 (In Press).

HONORS/AWARDS/PRIZES

Prof. Henrik Schmidt has been awarded the *Pioneers of Underwater Acoustics Medal* of the Acoustical Society of America, to be presented at the 150th Meeting of the ASA, Oct. 17-21, 2005 in Minneapolis, MN.